

# Nuclear effects and neutron structure in deeply virtual Compton scattering off $^3\text{He}$

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**Abstract.** The study of nuclear generalized parton distributions (GPDs) could be a crucial achievement of hadronic physics since they open new ways to obtain new information on the structure of bound nucleons, in particular, to access the neutron GPDs. Here, the results of calculations of  $^3\text{He}$  GPDs in Impulse Approximation are presented. The calculation of the sum of GPDs  $H + E$ , and  $\tilde{H}$ , with the correct limits, will be shown. These quantities, at low momentum transfer, are largely dominated by the neutron contribution so that  $^3\text{He}$  is an ideal target for these kind of studies. Nevertheless the extraction of neutron information from future  $^3\text{He}$  data could be non trivial. A procedure, which takes into account nuclear effects encoded in IA, is presented. The calculation of  $H, E$  and  $\tilde{H}$  allows also to evaluate the cross section asymmetries for deeply virtual compton scattering at Jefferson Lab kinematics. Thanks to these observations, DVCS off  $^3\text{He}$  could be an ideal process to access the neutron information in the next future.

## 1. Introduction

In the last few years, generalized parton distributions (GPDs) draw the attention of the hadronic physics community since they allow to obtain new information on the parton structure of hadrons [1, 2, 3]. GPDs encode the non perturbative hadron structure in some peculiar hard exclusive processes. In particular, these quantities could give fundamental information on hadrons, such as the 3-dimensional structure of these systems at parton level [4]. In this work we focus on the future possibility of shedding some light on the so called “Spin crisis” problem. In principle this could be realized thanks the relation between the GPDs and the total angular momentum of partons inside the hadrons: by subtracting from it the quark helicity contribution to the hadron spin, it would be possible to access, for the first time, their orbital angular momentum (OAM) [2, 3].

The golden process to study these quantities is the deeply virtual compton scattering (DVCS), which is described, at leading twist, mainly by  $H$ ,  $E$  and  $\tilde{H}$  GPDs. This reaction could be sketched in the following way:  $eH \longrightarrow e'H'\gamma$  when  $Q^2 \gg M^2$  ( $Q^2 = -q \cdot q$  is the momentum transfer between the leptons beam  $e$  and  $e'$ ,  $\Delta^2$  the one between hadrons  $H$  and  $H'$  with momenta  $P$  and  $P'$ , and  $M$  is the nucleon mass). Another important kinematical variable is the so called skewedness,  $\xi = -\Delta^+/(P^+ + P'^+)$ <sup>1</sup>. Even though DVCS is the cleanest process to access the

<sup>1</sup> In this paper,  $a^\pm = (a^0 \pm a^3)/\sqrt{2}$ .

GPDs, the measurement of these quantities is still a theoretical and experimental challenge. Despite of these difficulties, data for proton and nuclear targets are being analyzed [5, 6].

The study of hard exclusive processes off nuclear targets, and the relative measurement of their GPDs, can give new information on possible medium modifications of the structure of bound nucleons (see Ref. [7]). In other words, these studies are very important to have new information on the origin of the so called EMC effect, an impossible task with the usual DIS studies. To this aim few-body systems play a special role since, for these targets, realistic treatments are possible and exotic effects could be, in principle, distinguished from the conventional ones. The use of nuclear targets are also necessary, clearly, to study and to obtain information on the neutron GPDs and, in particular, this investigation is the main purpose of this work.

## 2. $^3\text{He}$ GPDs in impulse approximation

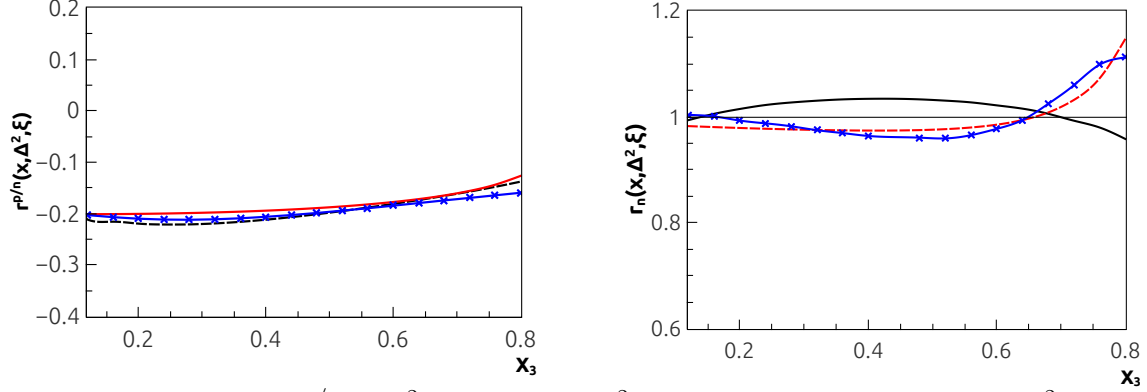
In order to have a complete flavor decomposition of the GPDs, the proton data are clearly not sufficient so that the study of the neutron GPDs has become a priority of the hadron physicists and, as mentioned in the last section, this could be realized by using nuclear targets. To this aim, among the light nuclei,  $^3\text{He}$  is an ideal ones due its spin structure, in fact almost the 90% of the  $^3\text{He}$  spin comes from the neutron one [8, 9]. In particular we expect that this nuclear system could be considered a unique target to extract the neutron  $E_q^n$  GPD. In fact this quantity is, at low momentum transfer, related to the anomalous magnetic moments which, for proton and neutron assumes the following values  $k_p \sim 1.79 \mu_N$  and  $k_n \sim -1.91 \mu_N$  (where  $\mu_N$  is the nuclear magneton) respectively so they are similar in size but with opposite sign. This properties make isoscalar nuclei, such as  $^2\text{H}$  and  $^4\text{He}$ , not useful to extract the  $E_q^n$  GPD of the neutron since the proton contribution basically cancels the neutron one (see Ref.[7, 10] for relevant work on isoscalar light nuclei). In the  $^3\text{He}$  case, the situation is completely different and to understand this feature it is sufficient to consider the dipole magnetic moment of  $^3\text{He}$  and of the neutron:  $\mu_3 \simeq -2.13 \mu_N$  and  $\mu_n \simeq -1.91 \mu_N$ , which are very similar and would be equal if an independent particle model were valid for  $^3\text{He}$ . Thanks to these properties,  $^3\text{He}$  simulates an effective polarized free neutron target so that it could be used to extract neutron information by properly taking into account nuclear effects as in the DIS case, see Ref. [9]. From this analysis we expect that the sum  $\tilde{G}_M^{3,q}(x, \Delta^2, \xi) = H_q^3(x, \Delta^2, \xi) + E_q^3(x, \Delta^2, \xi)$ , related to the contribution of the parton of flavor  $q$  to the dipole magnetic moment of  $^3\text{He}$ , and  $\tilde{H}_q^3(x, \Delta^2, \xi)$ , associated to polarized targets, should be both largely dominated by the neutron contribution at low momentum transfer. Here it will be just presented the main passages of the formal calculation of the  $^3\text{He}$  GPDs.

For a  $\frac{1}{2}$  spin target the main quantity which describes the non perturbative hadron structure in the analyzed process is the so called light cone correlator which is parametrized, at leading twist, by the GPDs  $H_q(x, \Delta^2, \xi)$  and  $E_q(x, \Delta^2, \xi)$  in the unpolarized case:

$$F_{s's}^{q,A,\mu}(x, \Delta^2, \xi) = \int \frac{dz^-}{4\pi} e^{ix\bar{P}^+z^-} {}_A\langle P's' | \hat{O}_q^\mu | Ps \rangle_A |_{z^+=0, z_\perp=0} = \frac{1}{2\bar{P}^+} \left[ H_q^A(x, \Delta^2, \xi) \bar{u}(P', s') \gamma^\mu u(P, s) + E_q^A(x, \Delta^2, \xi) \bar{u}(P', s') \frac{i\sigma^{\mu\alpha} \Delta_\alpha}{2m} u(P, s) \right] \quad (1)$$

while for the polarized case one has:

$$\tilde{F}_{s's}^{q,A,\mu}(x, \Delta^2, \xi) = \int \frac{dz^-}{4\pi} e^{ix\bar{P}^+z^-} {}_A\langle P's' | \tilde{O}_q^\mu | Ps \rangle_A |_{z^+=0, z_\perp=0} = \frac{1}{2\bar{P}^+} \left[ \tilde{H}_q^A(x, \Delta^2, \xi) \bar{u}(P', s') \gamma^\mu \gamma^5 u(P, s) + \tilde{E}_q^A(x, \Delta^2, \xi) \bar{u}(P', s') \frac{i\sigma^{\mu\alpha} \gamma_5 \Delta_\alpha}{2m} u(P, s) \right] \quad (2)$$



**Figure 1.** The ratio  $r^{p/n}(x, \Delta^2, \xi)$  and  $r_n(x, \Delta^2, \xi)$  evaluated in this region:  $-\Delta^2 = 0.1 \text{ GeV}^2$  and  $\xi = 0$ , where here  $x_3 = (M_3/M)x$  and using the models of Refs.[17, 19, 20]

where the initial (final) momentum and helicity are  $P(P')$  and  $s(s')$ , respectively, and  $\hat{O}_q^\mu = \bar{\psi}_q(-\frac{z}{2}) \gamma^\mu \psi_q(\frac{z}{2})$ ,  $\tilde{O}_q^\mu = \bar{\psi}_q(-\frac{z}{2}) \gamma^\mu \gamma_5 \psi_q(\frac{z}{2})$ ,  $\bar{P} = (P + P')/2$ ,  $\psi_q$  is the quark field,  $m$  is the hadron mass.

Since we have to rely on a  $^3\text{He}$  wave function, it is necessary to perform a non relativistic limit of the light cone correlator in order to have a complete consistency. Thanks to this procedure, simple relations between the GPDs and spin components of the correlator were found (see Ref.[11] for details):

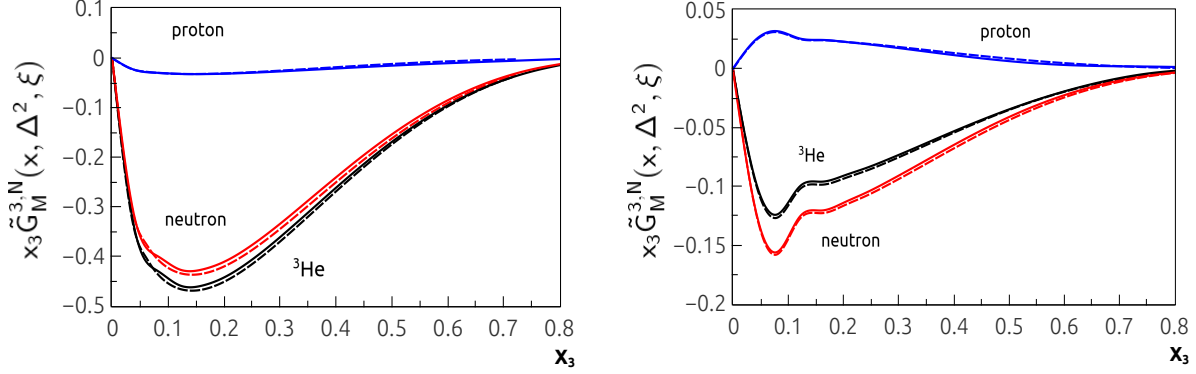
$$\begin{aligned} H_q^A(x, \Delta^2, \xi) &= \frac{\bar{P}^+}{m} F_{++}^{q,A,0}(x, \Delta^2, \xi) , \\ \tilde{G}_M^{A,q}(x, \Delta^2, \xi) &= \frac{2\bar{P}^+}{\Delta_z} F_{+-}^{q,A,1}(x, \Delta^2, \xi) . \\ \tilde{H}_q^A(x, \Delta^2, \xi) &= \frac{\bar{P}^+}{m} i \tilde{F}_{+-}^{q,A,2}(x, \Delta^2, \xi) \end{aligned} \quad (3)$$

It is remarkable that one of the quantities we are analyzing is the sum  $\tilde{G}_M^{3,q}(x, \Delta^2, \xi) = H_q^3(x, \Delta^2, \xi) + E_q^3(x, \Delta^2, \xi)$  which is also, in addition to the connection with the magnetic form factor (ff) of the hadron, a fundamental quantity thanks to its relation with the total angular momentum of partons inside the hadrons (Ji's sum rule [3]):

$$J_q^A = \int_{-1}^1 dx \, x \, \tilde{G}_M^{A,q}(x, 0, 0) \quad (4)$$

This result justifies our interest in the calculation of this particular combination of the GPDs. Starting from the NR relations, one can describe the light cone correlator in terms of quantities which depend on  $^3\text{He}$  wave function, by properly applying the IA (see Ref.[12] for details). Using then the same GPDs relations, Eqs.(3), for the free nucleonic contributions, one finds:

$$\tilde{G}_M^{3,q}(x, \Delta^2, \xi) = \sum_N \int dE \int d\vec{p} \, [P_{+-,+}^N - P_{+-,-}^N] (\vec{p}, \vec{p}', E) \frac{\xi'}{\xi} \tilde{G}_M^{N,q}(x', \Delta^2, \xi') \quad (5)$$



**Figure 2.** The GPD  $x_3 \tilde{G}_M^3(x, \Delta^2, \xi)$ , where  $x_3 = (M_3/M)x$  and  $\xi_3 = (M_3/M)\xi$ , shown in the forward limit (left panel) and at  $\Delta^2 = -0.1 \text{ GeV}^2$  and  $\xi_3 = 0.1$  (right panel), together with the neutron and the proton contribution. Solid lines represent the full IA result, Eq. (5), while the dashed ones correspond to the approximation Eq. (12).

and

$$\tilde{H}_q^3(x, \Delta^2, \xi) = \sum_N \int dE \int d\vec{p} [P_{++,++}^N - P_{++,--}^N](\vec{p}, \vec{p}', E) \frac{\xi'}{\xi} \tilde{H}_q^N(x', \Delta^2, \xi'), \quad (6)$$

where here  $x'$  and  $\xi'$ , the variables for the bound nucleon GPDs, have been introduced, with  $p$  ( $p' = p + \Delta$ ) its 4-momentum in the initial (final) state and proper components appear of the spin dependent, one body off diagonal spectral function:

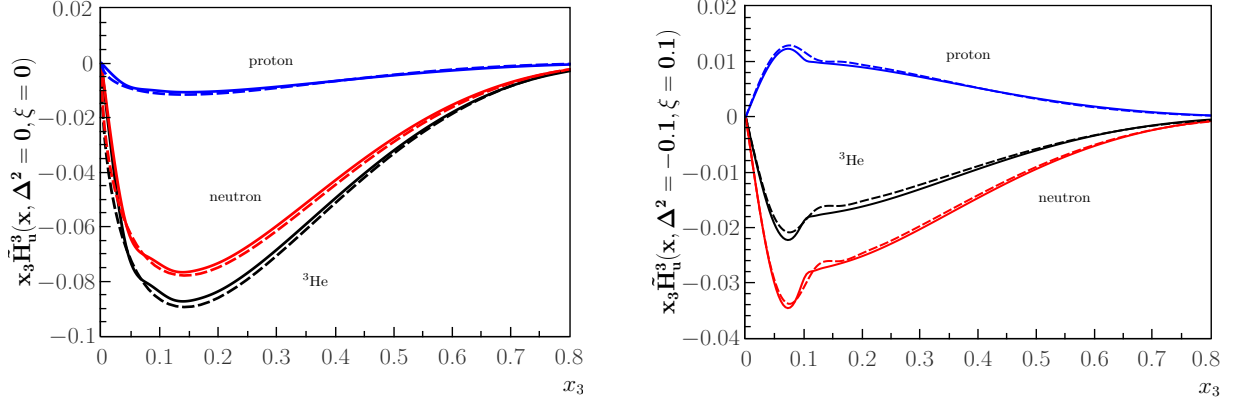
$$P_{SS',ss'}^N(\vec{p}, \vec{p}', E) = \frac{1}{(2\pi)^6} \frac{M\sqrt{ME}}{2} \int d\Omega_t \sum_{s_t} \langle \vec{p}' S' | \vec{p}' s', \vec{t}_{s_t} \rangle_N \langle \vec{p} s, \vec{t}_{s_t} | \vec{P} S \rangle_N. \quad (7)$$

Here  $E = E_{min} + E_R^*$ , where  $E_R^*$  is the excitation energy of the full interacting two-body recoiling system. The main ingredient appearing in the definition Eq. (7) is the intrinsic overlap integral

$$\langle \vec{p} s, \vec{t}_{s_t} | \vec{P} S \rangle_N = \int d\vec{y} e^{i\vec{p} \cdot \vec{y}} \langle \chi_N^s, \Psi_t^{s_t}(\vec{x}) | \Psi_3^S(\vec{x}, \vec{y}) \rangle \quad (8)$$

between the  $^3\text{He}$  wave function,  $\Psi_3^S$ , and the final state, described by two wave functions: *i*) the eigenfunction  $\Psi_t^{s_t}$ , with eigenvalue  $E = E_{min} + E_R^*$ , of the state  $s_t$  of the intrinsic Hamiltonian describing the system of two *interacting* nucleons with relative momentum  $\vec{t}$ , which can be either a bound or a scattering state, and *ii*) the plane wave representing the free nucleon  $N$  in IA. For a numerical evaluation of Eqs. (1) and (2), the overlaps, Eq. (4), appearing in Eq. (3) and corresponding to the analysis presented in Ref. [13] in terms of AV18 [14] wave functions [15], have been used. Clearly the accuracy of this calculation, since the NR relativistic spectral function has been used, will be of the order  $\mathcal{O}(\vec{p}^2/M^2, \vec{\Delta}^2/M^2)$ .

Since no data for  $^3\text{He}$  GPDs are actually available, the only possible checks for our calculations will be the GPDs properties, in particular the forward limit and the first moment. In Ref.[12] it has been illustrated that  $H_q^3(x, \Delta^2, \xi)$  fulfills these constraints while, in Ref.[11], the quantity



**Figure 3.** The GPD  $x_3 \tilde{H}_u^3(x, \Delta^2, \xi)$  for the flavor  $q = u$  shown in the forward limit (left panel) and at  $\Delta^2 = -0.1 \text{ GeV}^2$  and  $\xi_3 = 0.1$  (right panel), together with the neutron and the proton contribution. Solid lines represent the full IA result, Eq. (6), while the dashed ones correspond to the approximation Eq. (11).

$\sum_q \int dx \tilde{G}_M^{3,q}(x, \Delta^2, \xi) = G_M^3(\Delta^2)$ , which should give the magnetic ff of  ${}^3\text{He}$ , has been calculated, since no forward limit is defined for the  $E_q(x, \Delta^2, \xi)$  GPD. Our result is in agreement with the one-body part of the AV18 calculation, presented in Ref.[16], and also for  $-\Delta^2 \leq 0.15 \text{ GeV}^2$ , which is the relevant kinematics condition for the coherent DVCS at JLab, our results compare well with data. Concerning  $\tilde{H}_q^3(x, \Delta^2, \xi)$ , its first moment is the axial ff of  ${}^3\text{He}$  but, since this quantity is poorly known, the only possible check for this GPD is the forward limit, which is correctly recovered.

In order to present the main results for the calculations of  ${}^3\text{He}$  GPDs and estimating the proton and neutron contribution, describing the IA, it is necessary to explain some details on the used model for the free nucleonic GPDs, necessary to perform numerical evaluations.

### 3. Nucleonic models of GPDs

In this work, as pointed out in the previous section, we need to perform a numerical evaluation of  ${}^3\text{He}$  GPDs; in particular, as suggested by the behavior of the  ${}^3\text{He}$  wave function, these quantities should be dominated by the neutron contribution. This feature is provided by nuclear properties and should not be inferred from the nucleonic structure so that, for the calculation of  $\tilde{G}_M^3(x, \Delta^2, \xi)$ , we have used three completely different models:

- for our first calculation we have used a very simple model, Ref.[17], which fulfills all the properties of GPDs. In this particular case the  $\Delta^2$  dependence is factorized out from the  $x$  and  $\xi$  one by introducing the contribution of the quark of flavor  $q$  to the nucleonic ff:  $F_q(\Delta^2)$ . To this aim experimental values of  $F_1^{n,p}(\Delta^2)$  Dirac ff have been used [18] and a parametrization has been chosen in order to have a flavor decomposition of these quantities. This model has been properly extended to describe the  $E_q$  GPD (see Refs.[11] for details);
- we have also used a description of the nucleonic structure based on a constituent quark model (along the lines of Ref.[19]), valid therefore in the valance quarks region. This model is very different from the previous one, and it does not assume any kind of factorization;
- for further analysis, a simple version of the MIT model, Ref.[20], has been used. This is a very different scenario since, here, free relativistic confined quarks are described.

It is important to remark that our purpose is to estimate and to extract neutron information from  $^3\text{He}$  GPDs so our main interest is on the nucleonic contribution to these quantities, a feature rather independent on the nucleonic model chosen, as it will be shown in the next section. Therefore, for the moment being, for the  $\tilde{H}_q$  calculation, we have just extended the first model described above, where a factorization dependence on  $\Delta^2$  is assumed, by properly introducing a simple ansatz for the axial nucleonic ff,  $\tilde{F}_q(\Delta^2) = \frac{1}{\left(1 - \frac{\Delta^2}{M_A^2}\right)^2}$  where  $M_A \simeq 5.076 \text{ fm}^{-1}$  (see

Ref.[21] for details).

Clearly, if experiments were planned, more realistic models for nucleonic GPDs will be adopted and included into the scheme.

#### 4. Nucleonic contributions to $^3\text{He}$ GPDs

Thanks to the nuclear and the nucleonic model described in the previous sections, and the comfort of all positive checks, the  $^3\text{He}$  GPDs:  $\tilde{G}_M^3(x, \Delta^2, \xi) = \sum_q \tilde{G}_M^{3,q}(x, \Delta^2, \xi)$  and

$\tilde{H}_q^3(x, \Delta^2, \xi)$  will be presented. Concerning these quantities, we found that the neutron contribution largely dominates the  $^3\text{He}$  GPDs, at low momentum transfer, but, increasing  $\Delta^2$ , the proton contribution grows up, in particular for  $u$  flavor. For the quantity  $\tilde{G}_M^3(x, \Delta^2, \xi)$ , this peculiar behavior is governed by the magnetic ff of  $^3\text{He}$ , where the proton contribution is basically negligible for low  $\Delta^2$  but, increasing the momentum transfer, the size of the neutron contribution decreases (see Ref.[11]). For this reason, as already pointed out, since our interest is on the nucleonic contributions to  $^3\text{He}$  GPDs, we have analyzed the ratio  $r^{p/n}(x, \Delta^2, \xi) = \tilde{G}_M^{3,p}(x, \Delta^2, \xi)/\tilde{G}_M^{3,n}(x, \Delta^2, \xi)$  using the three different models described in the previous section. The result of this calculation shows and demonstrates that this quantity, and the relative nucleonic contributions to  $^3\text{He}$  GPDs, clearly depend on the nuclear effects encoded in the  $^3\text{He}$  wave function rather than the free nucleonic structure. In closing this section, let us remind that our calculations show how the neutron contribution largely dominates the  $^3\text{He}$  GPDs, both in the case of  $\tilde{G}_M^3$  and  $\tilde{H}^3$  in the kinematics region of  $-\Delta^2 \lesssim 0.1 \text{ GeV}^2$ , in particular for the  $d$  flavor case. Despite the limited validity of the region of IA and the neutron dominance, these studies could be a prerequisite for future experiments since the Ji's sum rule, which is the main information we are interested in, is only valid in the forward limit, so that it would be crucial to estimate GPDs at very low momentum transfer.

In spite of these promising results, a procedure to extract the neutron GPDs, from future  $^3\text{He}$  data, at different values of momentum transfer, is necessary since the relations found for the nuclear GPDs, Eqs.(5,6), are convolution-like equations involving a nuclear term, the off diagonal spectral function, and a nucleonic one, which is the free nucleonic GPD. In this scenario the extraction of the neutron could be not trivial.

#### 5. Extraction procedure of neutron GPDs from $^3\text{He}$

In this section the extraction procedure, will be presented, together with numerical results, which allows to obtain the neutron GPDs from future  $^3\text{He}$  data. To this aim it is sufficient to write the  $^3\text{He}$  GPDs in terms of the “light cone spin dependent off-forward momentum distributions”,  $h(g)_N^3(z, \Delta^2, \xi)$  which are peaked around  $z = 1$  close to the forward limit.

$$\tilde{H}_q^3(x, \Delta^2, \xi) = \sum_N \int_{x_3}^{\frac{M_A}{M}} \frac{dz}{z} h_N^3(z, \Delta^2, \xi) \tilde{H}_q^N\left(\frac{x}{z}, \Delta^2, \frac{\xi}{z}\right), \quad (9)$$

$$\tilde{G}_M^{3,q}(x, \Delta^2, \xi) = \sum_N \int_{x_3}^{\frac{M_A}{M}} \frac{dz}{z} g_N^3(z, \Delta^2, \xi) \tilde{G}_M^{N,q} \left( \frac{x}{z}, \Delta^2, \frac{\xi}{z}, \right). \quad (10)$$

Therefore, in the region delimited by  $x_3 \leq 0.7$ , one can approximate the full calculation of  $^3\text{He}$  GPDs with these new and simpler relations:

$$\begin{aligned} \tilde{H}_q^3(x, \Delta^2, \xi) &\simeq \sum_N \tilde{H}_q^N(x, \Delta^2, \xi) \int_0^{\frac{M_A}{M}} dz h_N^3(z, \Delta^2, \xi) \\ &= G_A^{3,p,point}(\Delta^2) \tilde{H}_q^p(x, \Delta^2, \xi) + G_A^{3,n,point}(\Delta^2) \tilde{H}_q^n(x, \Delta^2, \xi), \end{aligned} \quad (11)$$

$$\begin{aligned} \tilde{G}_M^{3,q}(x, \Delta^2, \xi) &\simeq \sum_N \tilde{G}_M^{N,q}(x, \Delta^2, \xi) \int_0^{\frac{M_A}{M}} dz g_N^3(z, \Delta^2, \xi) \\ &= G_M^{3,p,point}(\Delta^2) \tilde{G}_M^{p,q}(x, \Delta^2, \xi) + G_M^{3,n,point}(\Delta^2) \tilde{G}_M^{n,q}(x, \Delta^2, \xi), \end{aligned} \quad (12)$$

where here the axial (A) and magnetic (M) point like ffs have been defined:  $G_{A(M)}^{3,N,point}(\Delta^2) = \int_0^{\frac{M_A}{M}} dz h(g)_N^3(z, \Delta^2, \xi)$ .

These quantities would give the nucleon  $N = n, p$  contribution to the nuclear axial (magnetic) ff if protons and neutrons were point-like particles.

In the magnetic case, in the kinematics region under scrutiny here, we found that these quantities are rather independent on nuclear potential (see Ref.[11] for details) while, concerning the axial case, we found that these ffs, in the forward limit, reproduce the so called “effective polarizations” of protons ( $p_p$ ) and neutron ( $p_n$ ), whose values, using the AV18 potential, are:  $p_n = 0.878$  and  $p_p = -0.023$ . In this limit our results reproduce formally and numerically the formalism obtained in Ref.[9] for the polarized DIS off  $^3\text{He}$ . Starting from Eqs.(11,12) it is possible to extract the free neutron GPDs from the  $^3\text{He}$  ones.

$$\tilde{H}^{n,extr}(x, \Delta^2, \xi) \simeq \frac{1}{G_A^{3,n,point}(\Delta^2)} \left\{ \tilde{H}^3(x, \Delta^2, \xi) - G_A^{3,p,point}(\Delta^2) \tilde{H}^p(x, \Delta^2, \xi) \right\}, \quad (13)$$

$$\tilde{G}_M^{n,extr}(x, \Delta^2, \xi) \simeq \frac{1}{G_M^{3,n,point}(\Delta^2)} \left\{ \tilde{G}_M^3(x, \Delta^2, \xi) - G_M^{3,p,point}(\Delta^2) \tilde{G}_M^p(x, \Delta^2, \xi) \right\}. \quad (14)$$

In order to test these new relations, we have compared Eqs.(11,12) with the full calculation of  $^3\text{He}$  GPDs, Eqs.(5,6) respectively. The results show that the new equations, in the kinematical region where the IA is valid, approximate very well the full calculation for  $x \leq 0.7$ , where the DVCS can be experimentally analyzed at the JLab. In particular it is remarkable that the only theoretical ingredients for these calculations are the axial (magnetic) ffs which are under good theoretical control. With the comfort of this successful results, in order to simulate the extraction procedure, since no data for the  $^3\text{He}$  GPDs exist, we have compared the neutron GPDs extracted, from the approximated relations Eqs.(13, 14), with the free neutron GPDs used as input for the full calculation and using the same model for the proton GPDs. The results of this comparisons show that this procedure works perfectly for  $x \leq 0.7$ .

In order to have more accuracy of this analysis, we have studied the ratio  $r_n(x, \Delta^2, \xi) = \tilde{G}_M^{n,extr}(x, \Delta^2, \xi) / \tilde{G}_M^n(x, \Delta^2, \xi)$  in a region which is beyond the forward limit and we have evaluated it using three completely different nucleonic models [17, 19, 20]. This result shows that our extraction procedure is weakly dependent even on the free nucleonic model.

## 6. Conclusion

In closing, we have shown the  $^3\text{He}$  GPDs, which are dominated, at low momentum transfer, by neutron contribution and, due to the complicated relation between the nuclear and the nucleonic GPDs, we have proposed an extraction procedure of the neutron GPDs, which is able to take into account the nuclear effects encoded in the IA and which is rather independent on the free nucleonic model and nuclear potential. These successful results make the coherent DVCS off  $^3\text{He}$  an ideal process to access the neutron GPDs. If higher momentum transfer region will be experimentally accessed, our work could be implemented by including a relativistic treatment, such as the one in Ref. [22] and/or many body currents, going beyond the IA.

Now it will be possible to study the cross section asymmetries for the DVCS processes the JLab kinematics since, for a  $\frac{1}{2}$  spin target (see Ref.[23]), at leading twist, the three GPDs  $H, E$  and  $\tilde{H}$  will mainly contribute. We have therefore at hand all the ingredients to perform this completely new analysis.

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